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FULL-SCALE WIND-TUNNEL INVESTIGATION OF
WING-COOLING DUCTS
EFFECTS OF PROPELLER SLIPSTREAM

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SUMMARY

The investigation of finite span wing-cooling ducts in the N.A.C.A. full-scale wind tunnel has been extended to include a study of the effects of slipstream on the duct characteristics. Of particular interest was the amount of air furnished by the propellers for the ground-cooling condition.

The results indicate that the propeller slipstream is effective in generating a flow of air through the ducts for the ground condition. The direction of propeller rotation materially affects the quantity of flow through the duct. For the flight conditions the slipstream increases the air-flow quantities by small amounts.

INTRODUCTION

Engine-cooling systems without auxiliary fans or blowers are dependent upon the propeller slipstream for ground cooling. In order to determine the amount of cooling air that is available from this source for wing-cooling ducts such as investigated at this laboratory (references 1 to 3) further tests have been conducted in the full-scale wind tunnel.

Two propellers, driven through extension shafts by electric motors located within the wing, were added to the test wing of reference 3 to simulate a possible installation on a four-engine airplane in which a common cooling duct is placed between two engines.

In addition to treating the ground-cooling problem, this report includes data on the changes in duct characteristics due to slipstream effects in flight. Although the results presented herein are only strictly applicable to the particular propeller-duct arrangement investigated, it is believed that reliable estimates of the effects of propeller slipstream may be made for other arrangements by the use of the included tables and duct-velocity distribution graphs.

APPARATUS AND TESTS

The wing, radiator, and ducts used were identical with those of reference 3, and the same system of duct designations is followed. Figures 1 and 2 show the propeller arrangement provided for the investigation. Each of the two 69-inch diameter, three-blade propellers was driven through an extension shaft by a 15-horsepower electric motor located in the wing. Both propellers were of the left-hand type and their blades extended over 75 percent of the duct span. The axes of the extension shafts were parallel to and 1-1/2 inches above the N.A.C.A. 23017 center section chord line, and the plane of the propellers was 24 inches ahead of the center section leading edge. The propeller blade angle, measured at 0.75R, was 20 degrees for the ground cooling and climb conditions and 28 degrees for the high-speed condition. Propeller speed was held constant at 1,200 r.p.m. and the tunnel velocity varied from 0 to 100 miles per hour.

Lift, resultant drag, and power input to the propellers were measured for the plain and ducted wing. The air flow through the ducts was measured by the same procedure described in reference 3. To determine the effects of the direction of propeller rotation the air-flow distribution was measured across the full duct span at the duct outlet for a number of the test arrangements.

SYMBOLS

C_L , wing-lift coefficient.

ρ , air density.

A , area of propeller disk.

- D, propeller diameter.
- n, propeller speed.
- V, free stream velocity, or flight speed.
- V_R , duct velocity at radiator face.
- V_{R_0} , duct velocity at radiator face, static condition.
- V_{R_c} , duct velocity at radiator face, climb condition.
- V_s , slipstream velocity.
- T_c , thrust coefficient = $T/\rho V^2 D^2$.

RESULTS AND DISCUSSION

Ground cooling.-- For the ground-cooling condition the usual flow ratio V_R/V becomes V_{R_0}/V_s where V_{R_0} is the duct velocity at the radiator face for the static condition and V_s is the slipstream velocity equal to $\sqrt{2T/A\rho}$. The air-flow measurements for a slipstream velocity in the normal range of full-throttle ground operation are given in table I. For comparison the air flow through the same ducts previously obtained (reference 3) has been included for the climb condition. ($C_L = 0.7$ and V corresponding to $V/nD = 0.734$.)

A comparison of the flow measurements for the two conditions indicates that if a cooling duct is satisfactory for the climb condition it would provide, with the propeller arrangement of this investigation, about one-half the amount of air necessary for continuous full-throttle ground operation. The large extent to which the direction of the propeller rotation affects the quantity of flow through the duct for the ground condition is shown in figure 3 by surveys made at the duct outlet. It is apparent from these surveys that if the amount of air furnished by the two propellers operating in the same direction is not sufficient for the ground operation of an airplane, the quantity of cooling air may be greatly increased by locating the duct inlet in back of up-going propeller

blades. This might be accomplished by reversing the rotation of one of the propellers or by providing a separate cooling duct for each engine.

Cooling in flight.— The increase in air flow through the ducts due to the slipstream for flight conditions is shown in table II by a comparison of the ratios of V_R/V obtained in this investigation with those obtained from the tests without propellers of reference 3. It will be noted that for the climb condition the ducts with the 2a and 0 nose showed gains of from 3 to 11 percent while ducts with the 3 nose, below the leading edge of the wing, gave increases of about 14 percent. For the high-speed condition the slipstream increased the flow for the ducts with the 2a nose from 3 to 13 percent whereas for the ducts with the 0 nose the increases were much larger. The relative merits of the various ducts in the presence of the slipstream are the same as obtained from the power-off tests with the exception of the ducts with the 0 nose at the high-speed condition, where the flow becomes approximately equal to that of the ducts with the 2a nose.

The effect of the rotation of the propeller slipstream shown in figure 4 for the climb condition is, as would be expected, much less than for the static ground condition shown in figure 3. The shape of the flow distribution curves of figure 4 indicate, however, that the flow is increased to somewhat greater extent by the up-going propeller blades than by the down-going propeller blades.

During the take-off run the effect of the propeller slipstream decreases rapidly. This is illustrated (figure 5) for one duct arrangement from the static to the climb condition.

From a few measurements of power consumption of the ducts it was definitely indicated that despite the fact that the propellers increased the flow slightly there was no measurable increase in the duct drag. It is therefore recommended, until more extensive tests can be made, that the duct power coefficients of reference 3 be used.

CONCLUDING REMARKS

The results of this investigation show that with the propeller arrangement tested, the air flow through the cooling ducts for the ground condition is about half the amount required for continuous full-power engine operation. Duct velocity distribution measurements, however, indicate that a considerable increase in flow could be obtained if the entire duct inlet were located behind the up-going propeller blades.

For the flight condition the increases in flow due to the slipstream were not large for the types of ducts likely to be used. The slipstream caused no measurable increase in power consumption of the ducts.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 15, 1938.

REFERENCES

1. Silverstein, Abe, and Nickle, F. R.: Preliminary Full-Scale Wind-Tunnel Investigation of Wing Ducts for Radiators. N.A.C.A. Advance Confidential Memorandum Report, March 1938.
2. Harris, Thomas A., and Recant, Isidore G.: Investigation in the 7- by 10-Foot Wind Tunnel of Ducts for Cooling Radiators Within an Airplane Wing. N.A.C.A. Advance Confidential Memorandum Report, July 1938.
3. Nickle, F. R., and Freeman, Arthur B.: Full-Scale Wind-Tunnel Investigation of Wing-Cooling Ducts. N.A.C.A. Advance Confidential Memorandum Report, October 1938.

TABLE I - Ground-Cooling Characteristics of Ducts

 $(V_s = 69.8 \text{ f.p.s.})$

| Arrangement | Air flow for | | | |
|--------------|-------------------------|---------------|-------------------------|-------------------|
| | Ground condition | | Climb condition | |
| | V_{R_o} (ft./sec.) | V_{R_o}/V_s | V_{R_c} (ft./sec.) | V_{R_o}/V_{R_c} |
| 7.4-2a-8-61 | 13.9 | 0.20 | 29.0 | 0.48 |
| 7.4-2a-6-65 | 12.4 | .18 | 24.6 | .50 |
| 6.0-2a-8-61 | 11.0 | .16 | 27.3 | .40 |
| 6.0-2a-6-65 | 10.1 | .14 | 23.8 | .42 |
| 6.0-0-8-61 | 11.4 | .16 | 29.0 | .39 |
| 6.0-0-6-65 | 9.7 | .14 | 25.5 | .38 |
| 6.9-0-8-61 | 13.8 | .20 | 29.0 | .48 |
| 6.9-0-6-65 | 12.2 | .18 | 25.5 | .48 |
| 6.0-3-8-61 | 13.2 | .19 | 28.2 | .47 |
| 7.4-2a-B3-61 | 15.6 | .22 | 29.0 | .54 |
| F4-2a-8-61 | 15.6 | .22 | 28.2 | .55 |
| F4-2a-6-65 | 14.1 | .20 | 23.8 | .59 |
| F4-2a-B3-61 | 16.2 | .23 | 29.0 | .56 |
| F5-2a-B3-61 | 11.8 | .17 | 30.0 | .39 |
| 6.0-2a-B3-61 | 12.2 | .18 | 28.2 | .43 |

TABLE II - Effect of Power on Duct Velocity

| Arrangement | Thrust coeffi- cient, T _c | Flow ratio, V _R /V | | Arrangement | Thrust coeffi- cient, T _c | Flow ratio, V _R /V | |
|---|---|-------------------------------|--------------|--------------|---|-------------------------------|--------------|
| | | Power on | Power off | | | Power on | Power off |
| Climb - C _L = 0.7, V/nD = 0.734 | | | | | | | |
| 7.4-2a-8-61 | 0.1259 | 0.34 | 0.33 | 7.4-2a-B3-61 | 0.1246 | 0.36 | 0.33 |
| 7.4-2a-6-65 | .1238 | .30 | .28 | F4-2a-8-61 | .1279 | .34 | .32 |
| 6.0-2a-8-61 | .1258 | .33 | .31 | F4-2a-6-65 | .1250 | .30 | .27 |
| 6.0-2a-6-65 | .1229 | .29 | .27 | F4-2a-B3-61 | .1243 | .35 | .33 |
| 6.0-0-8-61 | .1268 | .34 | .33 | F5-2a-B3-61 | .1238 | .35 | .34 |
| 6.0-0-6-65 | .1269 | .30 | .29 | 6.0-2a-B3-61 | .1238 | .35 | .32 |
| 6.9-0-8-61 | .1252 | .35 | .33 | 6.0-3-8-61 | .1271 | .36 | .32 |
| 6.9-0-6-65 | .1238 | .30 | .29 | 6.0-3-6-65 | .1264 | .32 | .28 |
| High speed - C _L = 0.2, V/nD = 1.313 | | | | | | | |
| 4.6-2a-2-75 | 0.0152 | 0.17 | 0.16 | 4.6-2a-B1-61 | 0.0158 | 0.22 | 0.21 |
| 4.6-2a-4-70 | .0149 | .23 | .22 | 4.6-2a-B2-61 | .0161 | .30 | .28 |
| 6.0-2a-2-75 | .0163 | .17 | .15 | 6.0-2a-B1-61 | .0143 | .22 | .21 |
| 6.0-2a-4-70 | .0154 | .23 | .22 | 6.0-2a-B2-61 | .0146 | .30 | .29 |
| 4.9-0-4-70 | - | .22 | - | 3.3-0-B1-61 | .0152 | .20 | .16 |
| 6.0-0-2-75 | .0133 | .17 | .12 | 3.3-0-B2-61 | .0146 | .26 | .20 |
| 6.0-0-4-70 | .0131 | .21 | .17 | | | | |
| 4.4-3-4-70 | - | .14 | - | | | | |

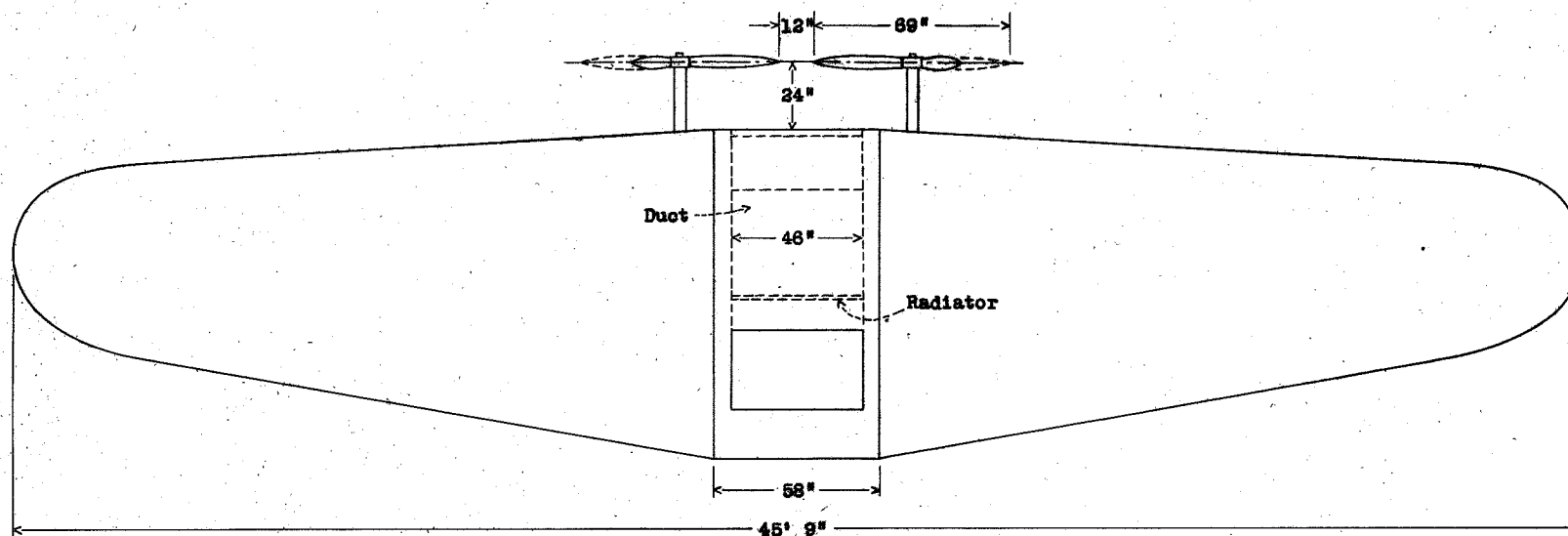


Figure 1.- Cooling wing with propellers.

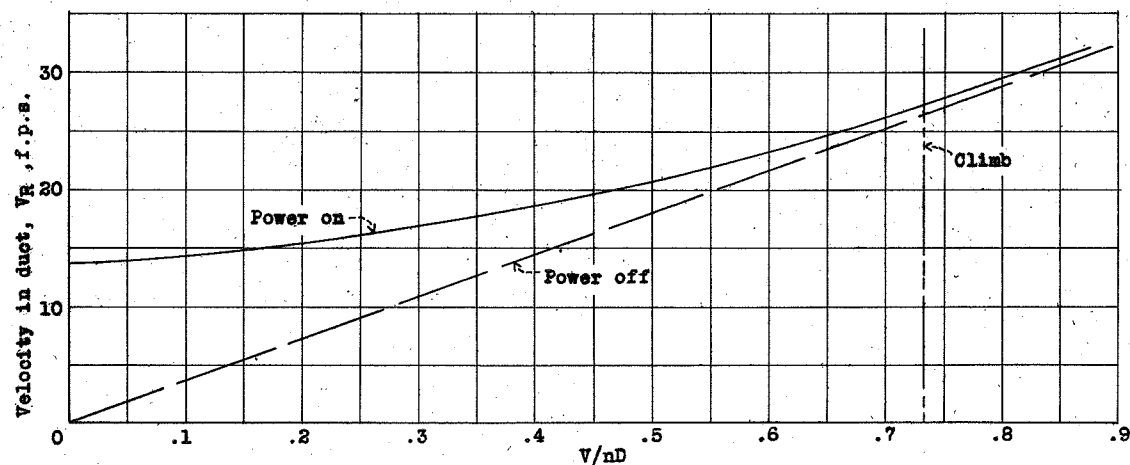


Figure 5.- Typical variation of duct velocity during take-off. Full-scale wind-tunnel duct cooling tests. Arrangement 7.4-2a-8-61; $nD = 115$.

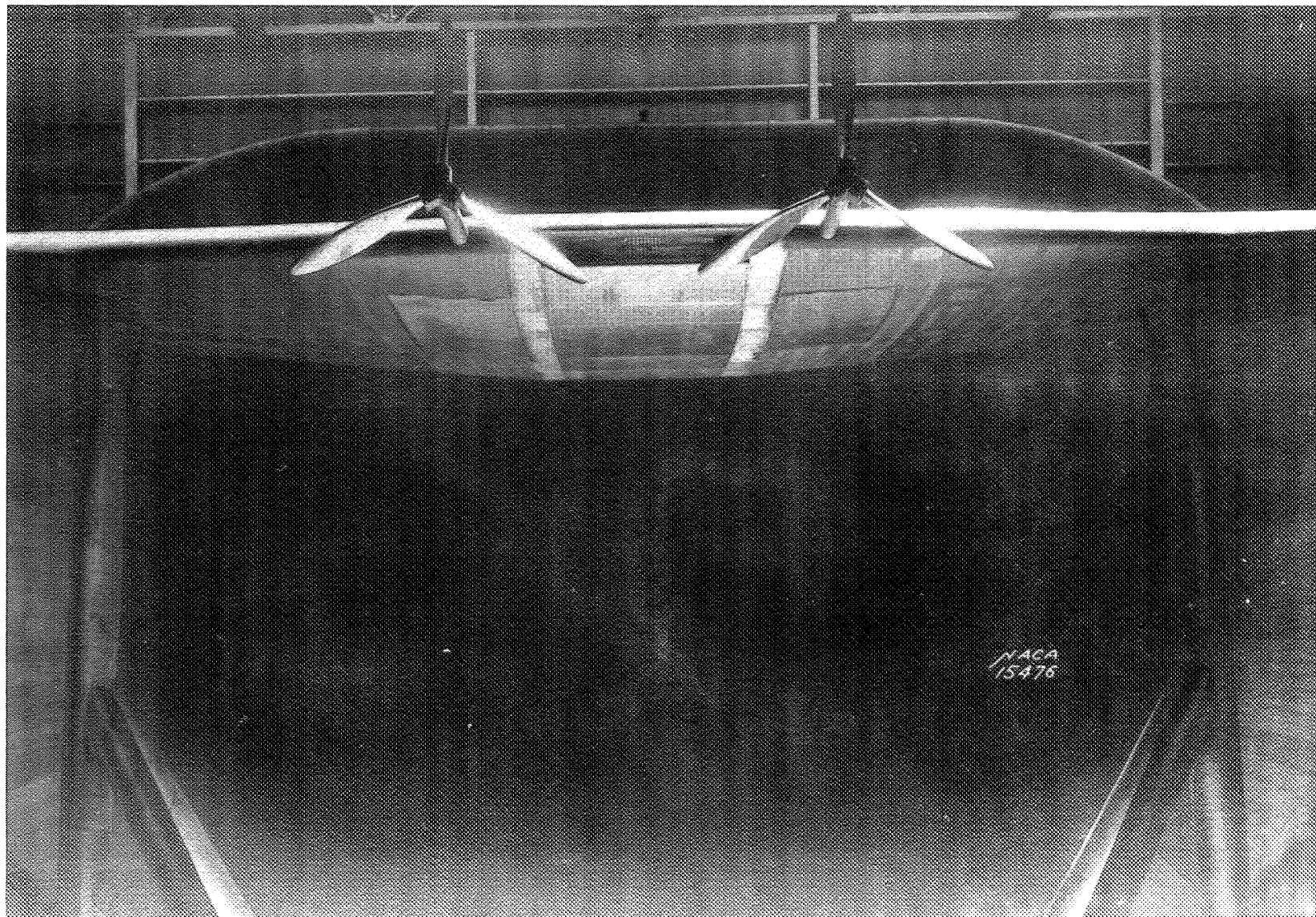


Figure 2.- Wing with duct and propellers mounted in full-scale wind tunnel.

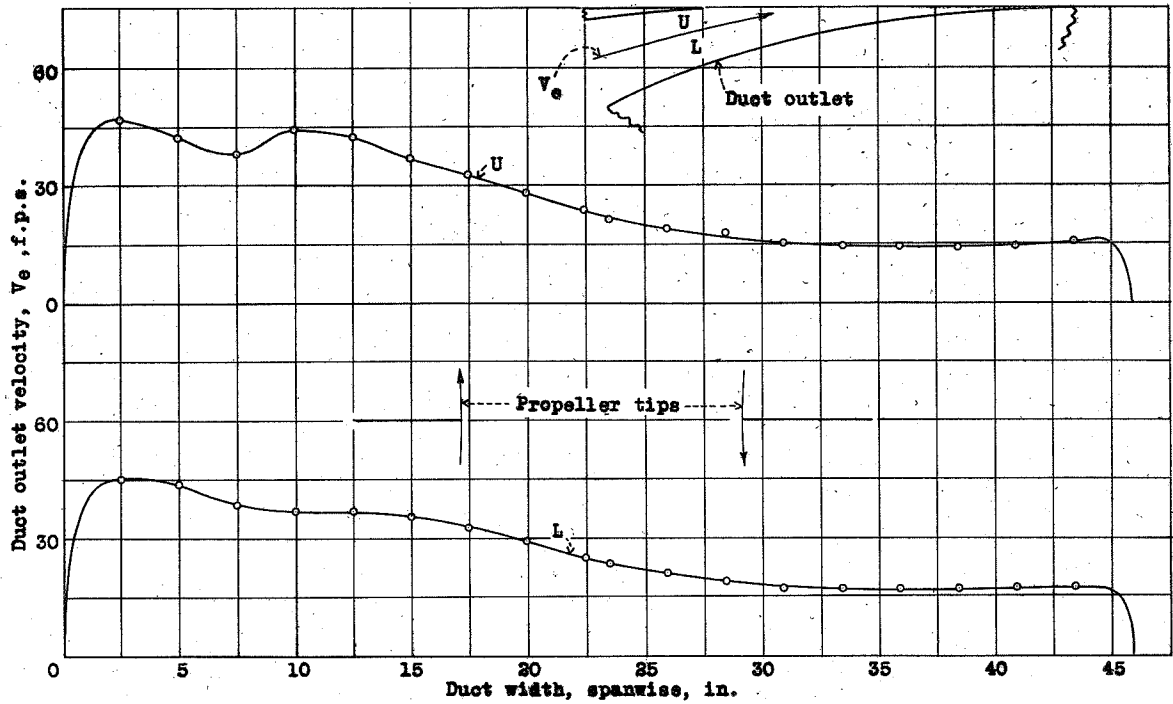


Figure 3.- Variation of duct velocity across duct with ground seeling.
Arrangement 7.4-2a-8-61; $V_g = 69.8$ f.p.s.; $nD = 115$.

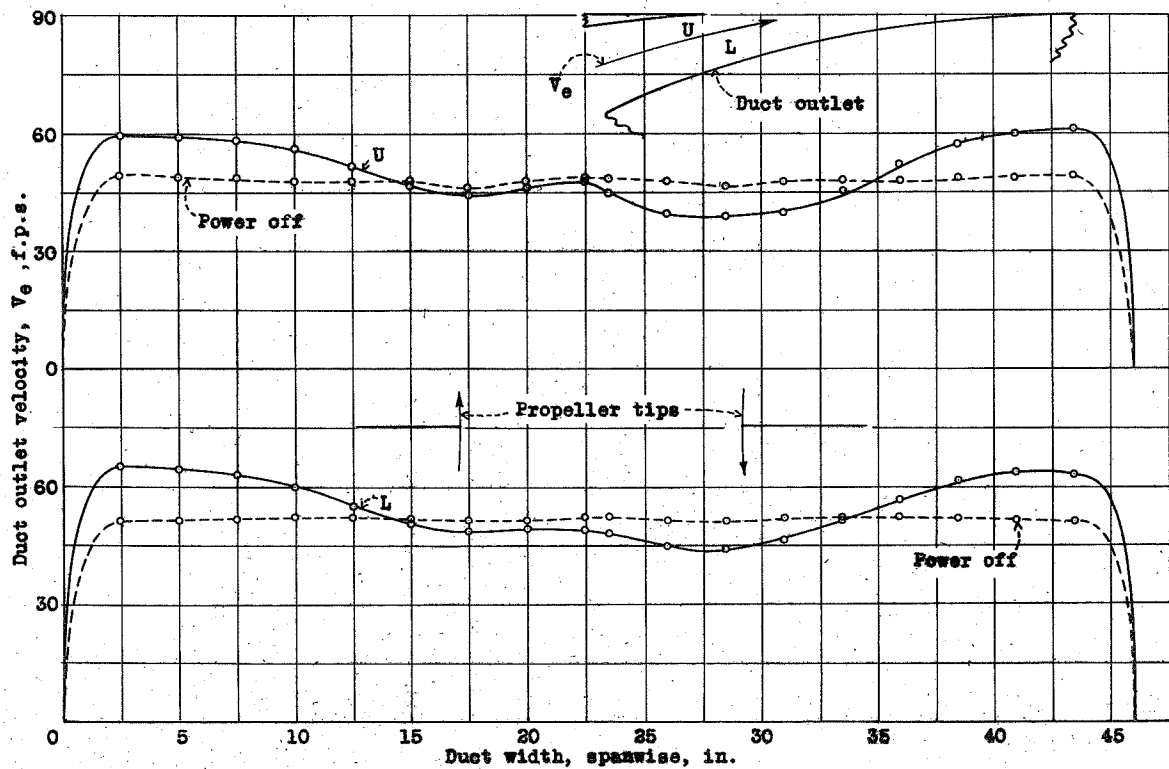


Figure 4.- Variation of duct velocity across duct at climb.
Arrangement 7.4-2a-8-61; $V/nD = 0.738$